Faculty of Engineering – Cairo University
Electronics and Electrical Communications Department
IC – Assignment 3

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1. The transfer function that satisfies the specifications:

In a bandpass filter (BPF), $[\omega_o^2 = \omega_1\omega_2 = \omega_3\omega_4]$, the symmetry is preserved by shifting the 5 MHz frequency to $\frac{20}{3}$MHz. This adjustment still meets the original specifications.

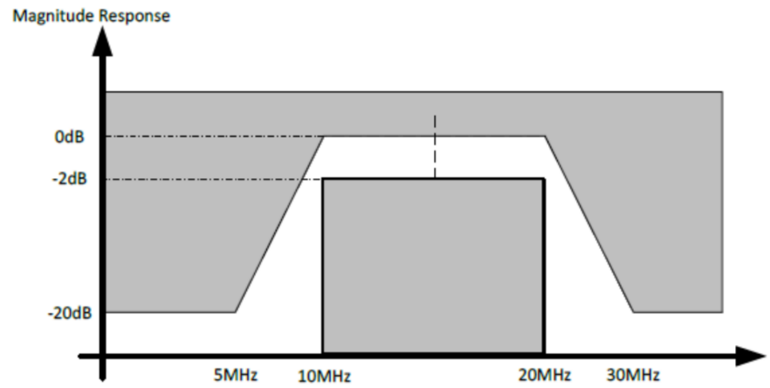


Figure 1 : BPF specification

Designing using Chebyshev Polynomial:

$$f_{o_{BPF}} = \sqrt{20 * 10} = 14.14\ MHz$$

$$BW = 20 - 10 = 10\ MHz$$

$$A_p = 20\log(1 + \epsilon^2) \leq 2\ dB$$

$$A_p = 1.4\ dB$$

$$\epsilon = 0.617$$

$$\omega_{o_{BPF}} = 2 * \pi * f_{o_{BPF}} = 88.85\ Mrad/sec$$

$$Q = 14.14/10 = 1.414$$

$$\Omega_s = \frac{\omega_4 - \omega_3}{BW} = \frac{7}{3}$$

$$A_s = 20\log(\epsilon) + 6(n-1) + 20n log(\Omega_s) = 20\ dB$$

$$\mathrm{n} = 2.26 = 3$$

$$\beta = \frac{1}{n}\sinh^{-1}\left(\frac{1}{\epsilon}\right) = 0.42$$

$$s_k = \sinh(\beta)\sin\left(\frac{2k-1}{2n}\pi\right) + i\cosh(\beta)\cos\left(\frac{2k-1}{2n}\pi\right)$$

$$s_{1,2} = -0.216 \pm i0.945$$

$$s_3 = -0.4324$$

The Normalized LPF:

$$H_{LPF} = \frac{0.4063}{(s + 0.4324)(s^2 + 0.432s + 0.93968)}$$

The Denormalization to BPF & of poles and zeros:

$$s_{BPF} = \frac{\omega_0}{BW}\left(\frac{s}{\omega_0} + \frac{\omega_0}{s}\right) = \frac{1.59 * 10^{-8}s^2 + 1.256 * 10^8}{s}$$

By substituting of each (s) in $H_{LPF}$by (s_{BPF}):

$$H_{BPF} = \frac{1 * 10^{23} * s^3}{\left(\begin{matrix} s^6 + 5.435 * 10^{7*}s^5 + 2.812 * 10^{16} * s^4 + 9.589 * 10^{23} * s^3 + \\ 2.22 * 10^{32} * s^2 + 3.388 * 10^{39} * s + 4.9223 * 10^{47} \end{matrix}\right)}$$

By using MATLAB, the poles and zeros:

```
Poles of the transfer function in Hz:
   1.0e+07 *

  -0.1424 + 1.9591i
  -0.1424 - 1.9591i
  -0.2163 + 1.3976i
  -0.2163 - 1.3976i
  -0.0738 + 1.0155i
  -0.0738 - 1.0155i

Gain Margin (dB):
    2.9181

Phase Margin (degrees):
  179.8062

Gain Crossover Frequency (Hz):
   9.8017e+06

Phase Crossover Frequency (Hz):
   1.4148e+07
```

Figure 3: Poles and Zeros.

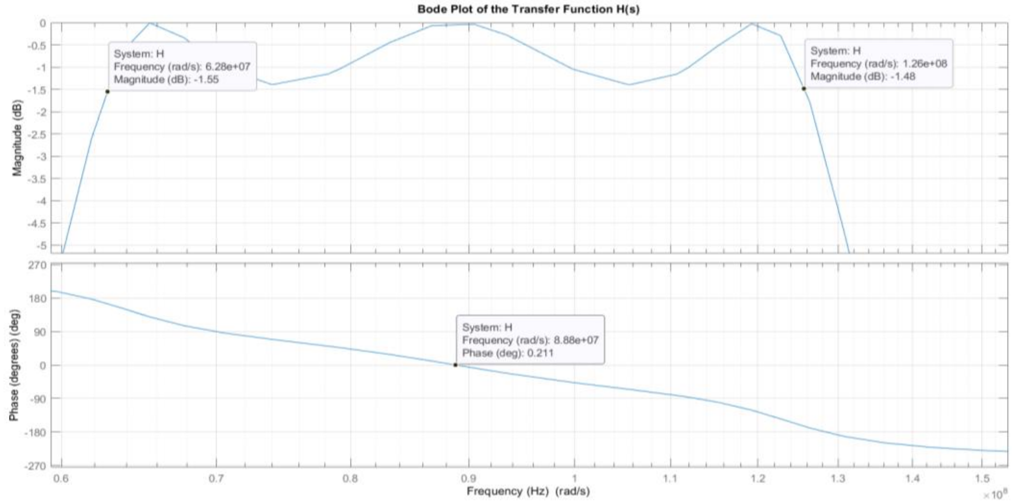


Figure 2: MATLAB Bode Plot

2. Circuit Design (Biquad filter topology):

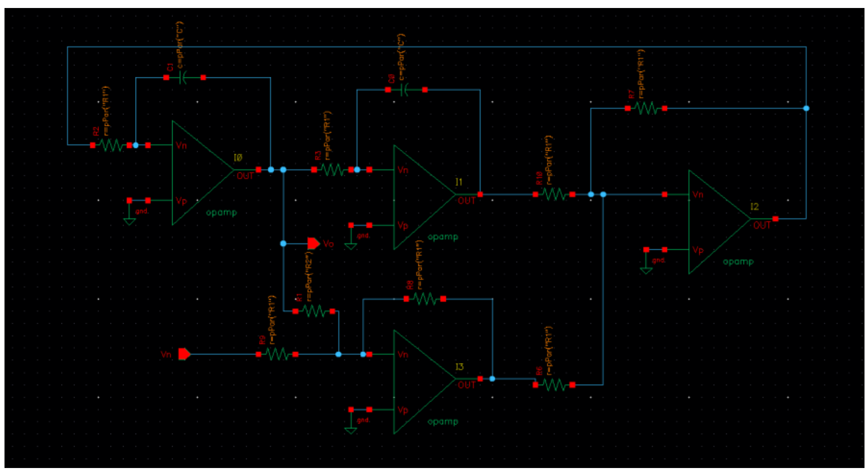


Figure 4: One Stage Biquad filter

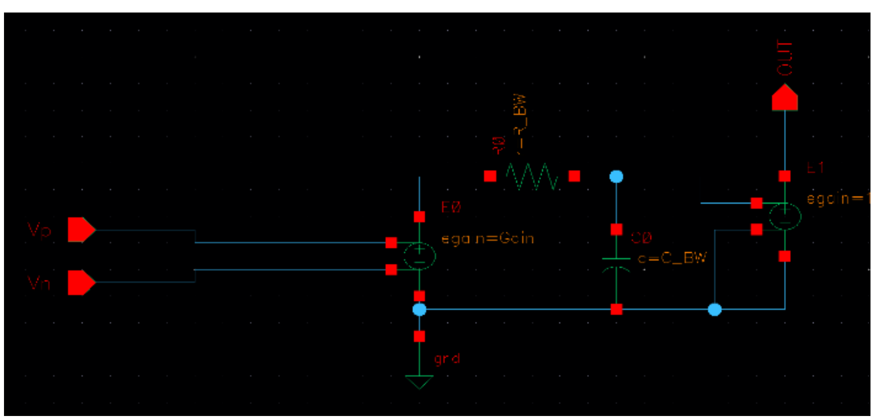


Figure 5 : Opamp model

The cascaded TF from $\mathbf{H_{BPF}}$:

```
Gain = nthroot((D/E^3),3);
p = [S6 S5 S4 S3 S2 S1 S0];
r = roots(p)

numerator = [Gain 0];

denominator1 = [1,-1*(r(1)+r(2)),r(1)*r(2)];
H1 = tf(numerator, denominator1)

denominator2 = [1,-1*(r(3)+r(4)),r(3)*r(4)];
H2 = tf(numerator, denominator2)

denominator3 = [1,-1*(r(6)+r(5)),r(5)*r(6)];
H3 = tf(numerator, denominator3)
```

```
H1 =

          4.65e07 s
  --------------------------
  s^2 + 1.79e07 s + 1.523e16

Continuous-time transfer function.

H2 =

          4.65e07 s
  ---------------------------
  s^2 + 2.718e07 s + 7.896e15

Continuous-time transfer function.

H3 =

          4.65e07 s
  ---------------------------
  s^2 + 9.279e06 s + 4.093e15
```

Figure 6: the cascaded TF

The Biquad BPF TF topology:

$$\mathrm{H_{BPF}} = \frac{-H_o * S\frac{1}{R1C}}{S^2 + S\frac{1}{QR1C} + \frac{1}{(R1C)^2}}$$

Design steps for $H_o = 1$, equal R, C topology and comparing H1, H2, H3 with the Biquad TF :

R1 = 1 (KΩ), R2 = $Q * R1$

TF	H1	H2	H3
R2 (KΩ)	6.8950	3.2694	6.8950
C (pF)	8.1025	11.254	15.631

Circuit Schematic:

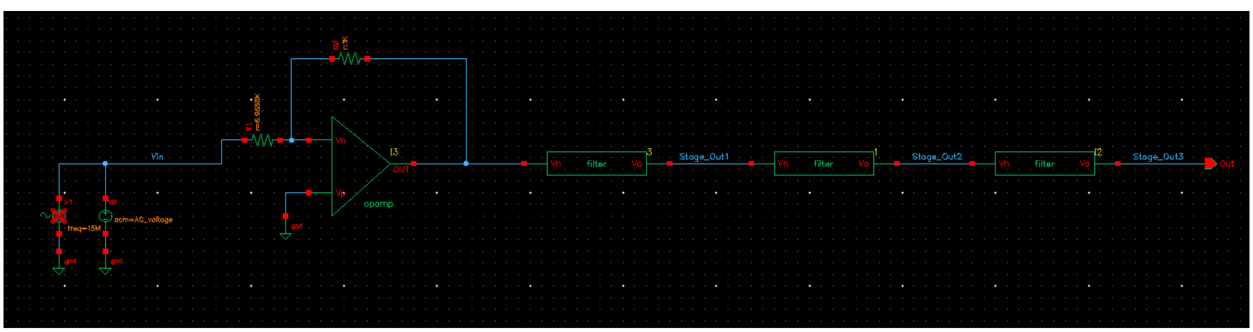


Figure 7: Circuit schematic

To normalize the filter, an op-amp was added initially to provide a gain of $\frac{1}{K1*K2*K2}$ to achieve overall gain $(4.65 * 10^7)^3$. Given the transfer function $TF = -\frac{RF}{R0}$, RF is set to 1kΩ and R0 is set to 6.97kΩ to achieve the required gain.

3. Simulation results:

AC Analysis:

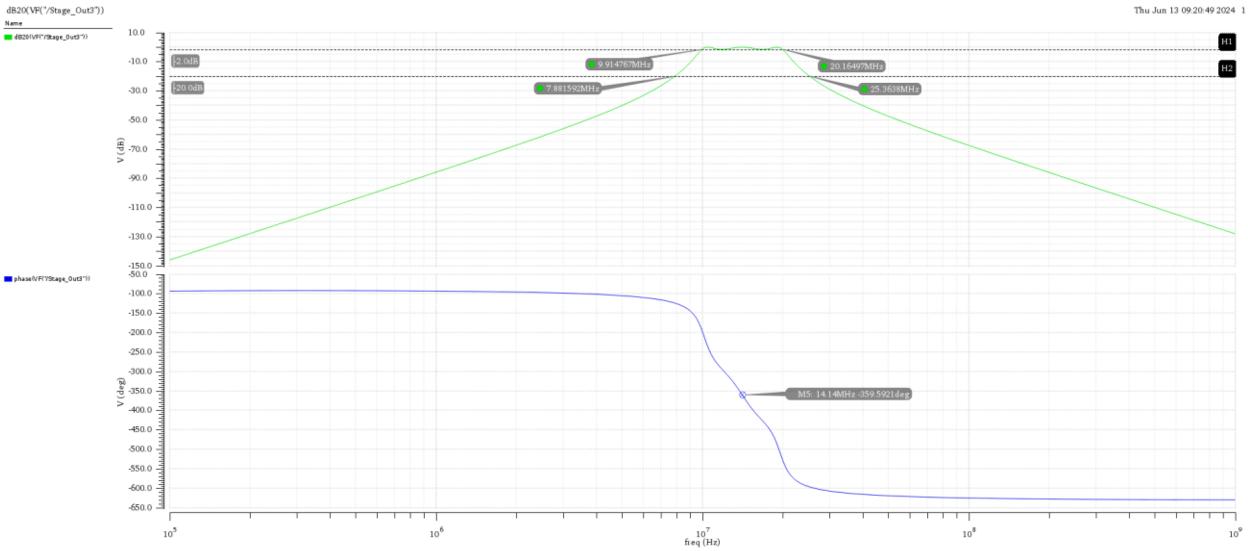


Figure 8 : Gain and Phase response (AC Analysis)

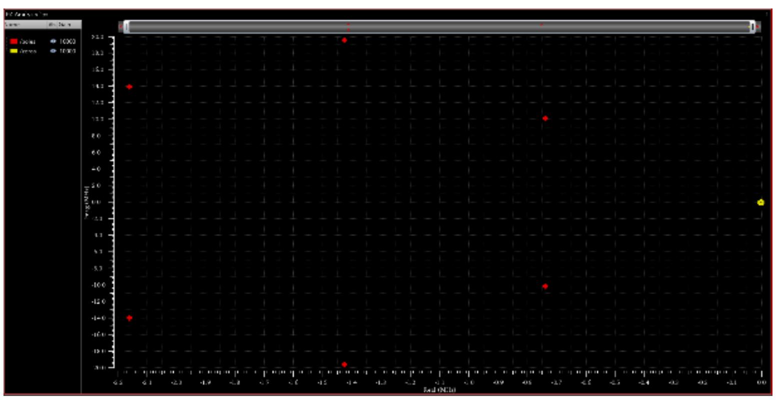
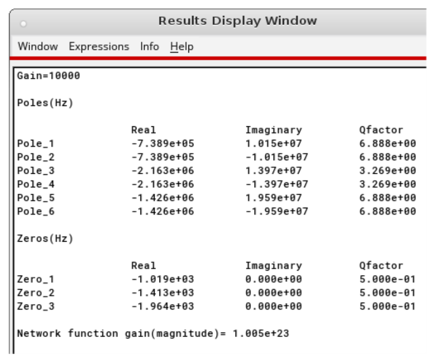


Figure 9 : Poles and Zeros analysis



Results Display Window

Window Expressions Info Help

Gain=10000

Poles(Hz)

	Real	Imaginary	Qfactor
Pole_1	-7.389e+05	1.015e+07	6.888e+00
Pole_2	-7.389e+05	-1.015e+07	6.888e+00
Pole_3	-2.163e+06	1.397e+07	3.269e+00
Pole_4	-2.163e+06	-1.397e+07	3.269e+00
Pole_5	-1.426e+06	1.959e+07	6.888e+00
Pole_6	-1.426e+06	-1.959e+07	6.888e+00

Zeros(Hz)

	Real	Imaginary	Qfactor
Zero_1	-1.019e+03	0.000e+00	5.000e-01
Zero_2	-1.413e+03	0.000e+00	5.000e-01
Zero_3	-1.964e+03	0.000e+00	5.000e-01

Network function gain(magnitude)= 1.005e+23

Figure 10 : Poles and Zeros Values

- As shown Magnitude response meets our expectations.
- **Poles**: Same as in hand analysis Values match our calculations.
- **Zeros**: we noticed that all zeros aren't exactly at zero but it has very small values compared to poles, so their effect on our response is negligible.

Because that the used op-amps aren't ideal and some mismatches.

1- Center frequency=14.14MHZ

2-phase at fc=-359.5921deg

3-BW=11MHZ

Output referred noise Analysis:

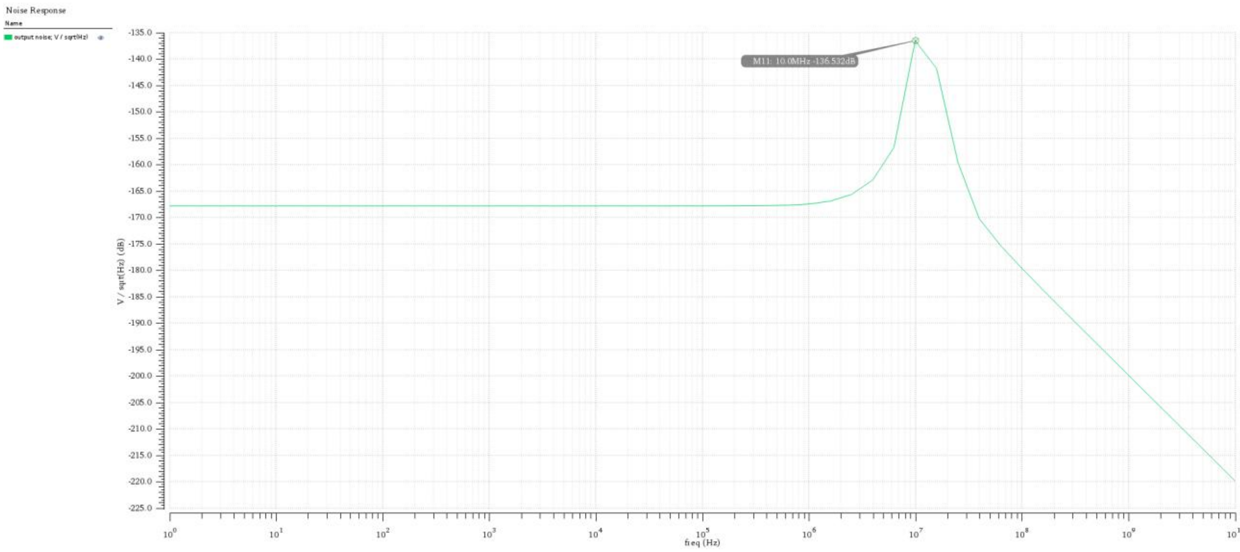


Figure 11 : Output referred noise in dB

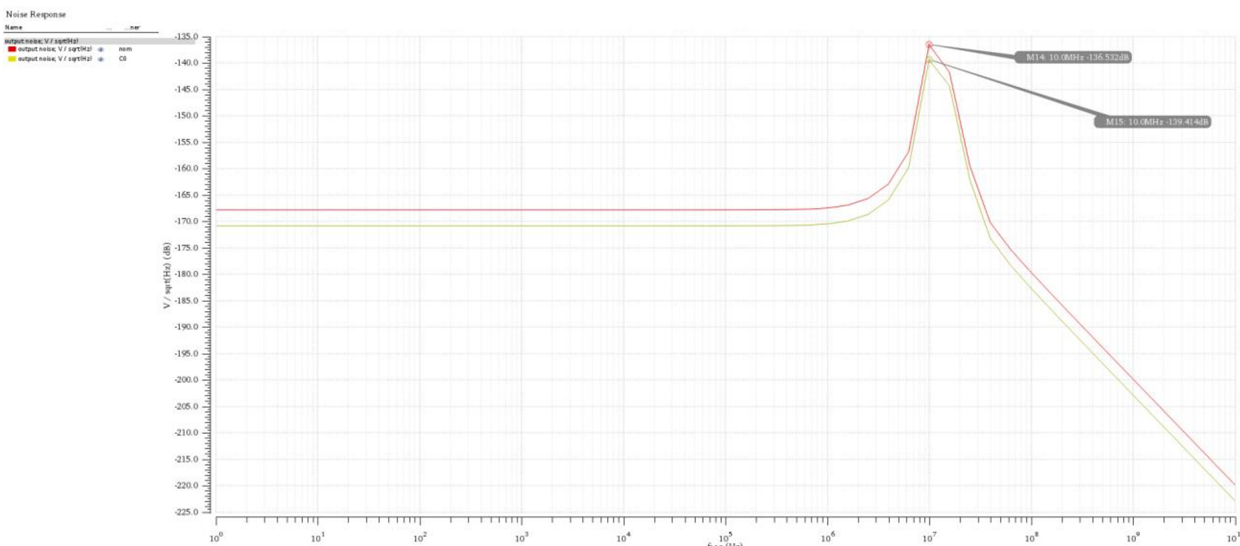


Figure 12 : Output referred noise after reducing R TO 0.5R

- 1Maximum output-referred noise is =149.065 $\mathrm{nV}/sqrt(\mathrm{HZ})$ at frequency =10MHZ
- After reducing the value of resistance by 50% of its primary value we noticed that:
- Output-referred noise decreased by almost $1/\sqrt{2}$ compared to the primary value and Maximum output-referred noise is =106.978 $\mathrm{nV}/sqrt(\mathrm{HZ})$ at frequency =10MHZ.
- There is a trade-off between the noise and power consumption as when we reduce the resistance the noise will decrease and power consumption will increase.

Transient response analysis:

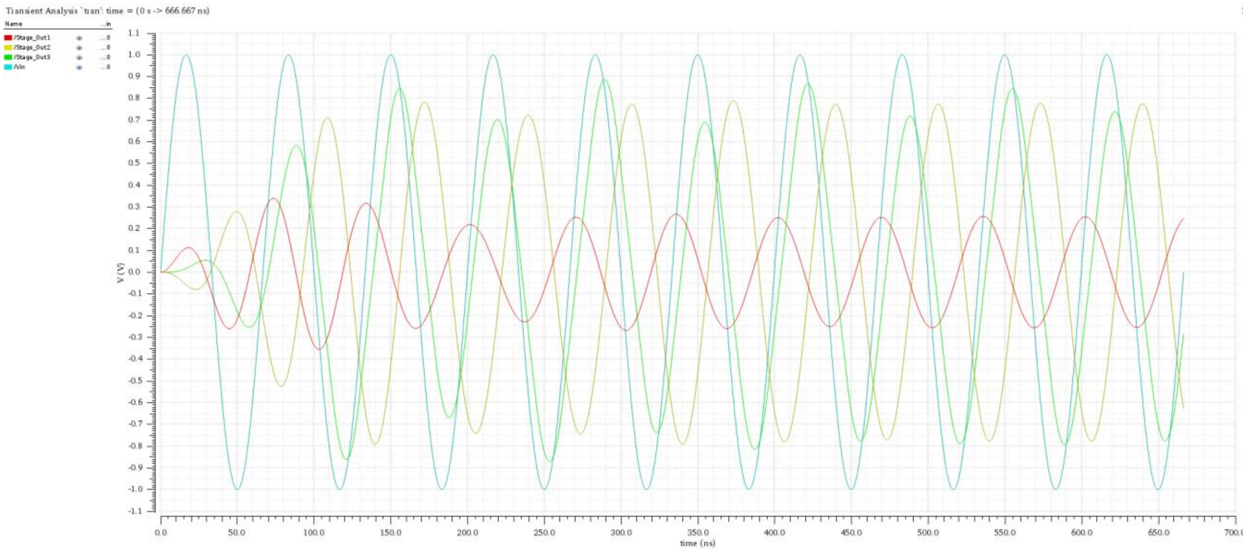


Figure 13 : Transient response

DFT:

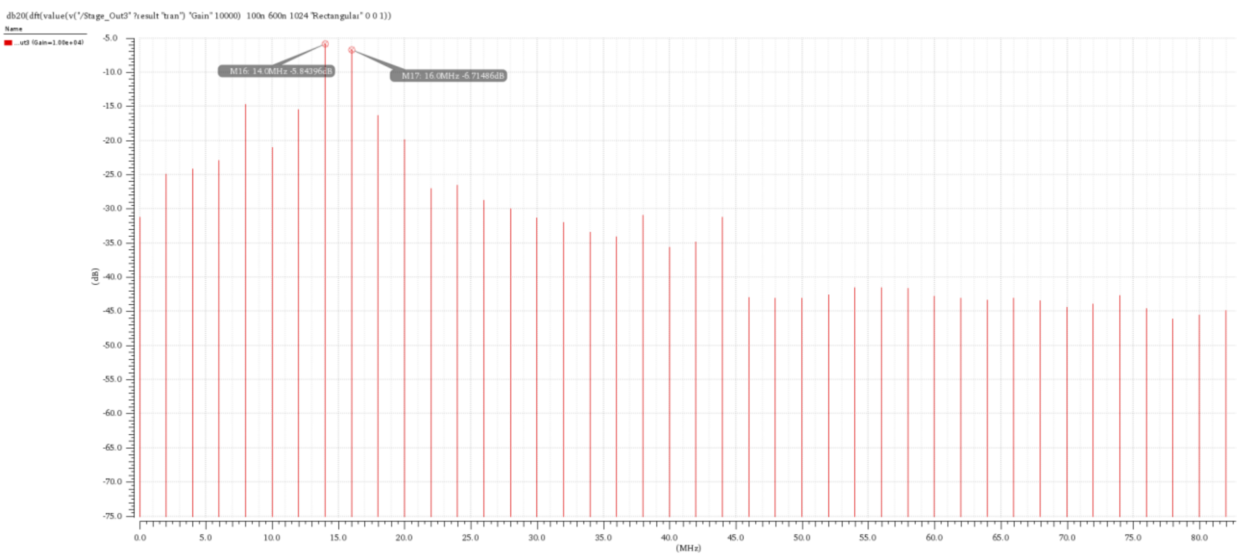


Figure 14 : DFT

DFT Varying all capacitors by ±15%

Comment: Cap (-15% change):

The transfer function has been changed due to the changing in caps values, this means that TF has shifted to high frequency because each stage will shift $\omega_0{}^2 = \frac{1}{R_1{}^2C^2}$ but quality factor will remain the same $Q = \frac{R_2}{R_1}$.

Cap (+15% change):

The transfer function has been changed due to the changing in caps values, this means that TF has shifted to lower frequency because each stage will shift $\omega_0{}^2 = \frac{1}{R_1{}^2C^2}$ but quality factor will remain the same $Q = \frac{R_2}{R_1}$.

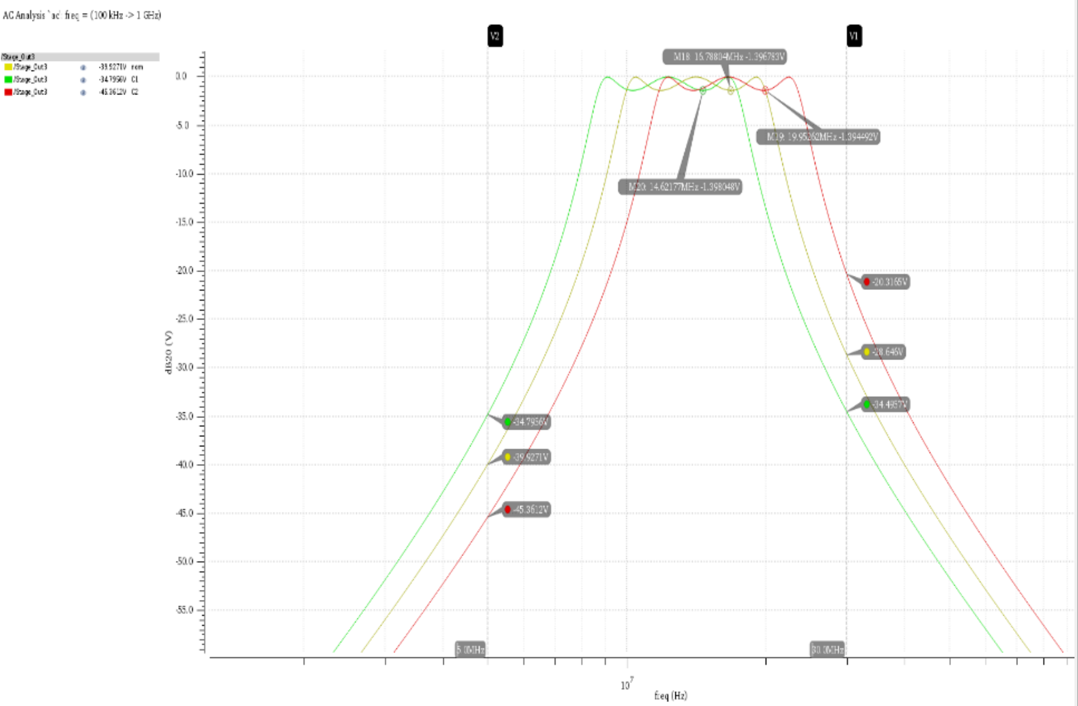


Figure 15 : 15% Caps gain

```
CS1=6.88713e-12,CS2=9.5659e-12,CS3=1.32863e-11

Poles(Hz)

                  Real            Imaginary       Qfactor
Pole_1            -8.693e+05      1.194e+07       6.888e+00
Pole_2            -8.693e+05      -1.194e+07      6.888e+00
Pole_3            -2.545e+06      1.644e+07       3.269e+00
Pole_4            -2.545e+06      -1.644e+07      3.269e+00
Pole_5            -1.677e+06      2.304e+07       6.888e+00
Pole_6            -1.677e+06      -2.304e+07      6.888e+00

Zeros(Hz)

                  Real            Imaginary       Qfactor
Zero_1            -1.198e+03      0.000e+00       5.000e-01
Zero_2            -1.664e+03      0.000e+00       5.000e-01
Zero_3            -2.311e+03      0.000e+00       5.000e-01

Network function gain(magnitude)= 1.637e+23

CS1=8.1025e-12,CS2=1.1254e-11,CS3=1.5631e-11

Poles(Hz)

                  Real            Imaginary       Qfactor
Pole_1            -7.389e+05      1.015e+07       6.888e+00
Pole_2            -7.389e+05      -1.015e+07      6.888e+00
Pole_3            -2.163e+06      1.397e+07       3.269e+00
Pole_4            -2.163e+06      -1.397e+07      3.269e+00
Pole_5            -1.426e+06      1.959e+07       6.888e+00
Pole_6            -1.426e+06      -1.959e+07      6.888e+00

Zeros(Hz)

                  Real            Imaginary       Qfactor
Zero_1            -1.018e+03      0.000e+00       5.000e-01
Zero_2            -1.414e+03      0.000e+00       5.000e-01
Zero_3            -1.964e+03      0.000e+00       5.000e-01

Network function gain(magnitude)= 1.005e+23

CS1=9.31787e-12,CS2=1.29421e-11,CS3=1.79756e-11

Poles(Hz)

                  Real            Imaginary       Qfactor
Pole_1            -6.425e+05      8.828e+06       6.888e+00
Pole_2            -6.425e+05      -8.828e+06      6.888e+00
Pole_3            -1.881e+06      1.215e+07       3.269e+00
Pole_4            -1.881e+06      -1.215e+07      3.269e+00
Pole_5            -1.240e+06      1.703e+07       6.888e+00
Pole_6            -1.240e+06      -1.703e+07      6.888e+00

Zeros(Hz)

                  Real            Imaginary       Qfactor
Zero_1            -8.853e+02      0.000e+00       5.000e-01
Zero_2            -1.230e+03      0.000e+00       5.000e-01
Zero_3            -1.708e+03      0.000e+00       5.000e-01

Network function gain(magnitude)= 6.609e+22
```

Figure 16 : Values

Varying capacitors in 1st section by ±2%

Comment:

Transfer function had been slightly changed due to the small change in caps in first sec values, which leads to small shift in the frequency response of the filter, and small change in the locations of poles and zeros.

Cap (-2% change):

This means that TF has shifted slightly to high frequency because each stage will shift $\omega_0{}^2 = \frac{1}{R_1{}^2C^2}$ but quality factor will remain the same $Q = \frac{R_2}{R_1}$.

Cap (+2% change):

This means that TF has shifted slightly to low frequency because each stage will shift $\omega_0{}^2 = \frac{1}{R_1{}^2C^2}$ but quality factor will remain the same $Q = \frac{R_2}{R_1}$.

We notice that this small change in CAP value will be unobservable in output response but from our observations we can see that this change has a high effect because cascade of biquads highly sensitivity to component mismatch.

..

Parameter	Nominal	C5	C6
CS1	8.102p	8.265p	7.94p

Figure 17 : 1st Capacitors value

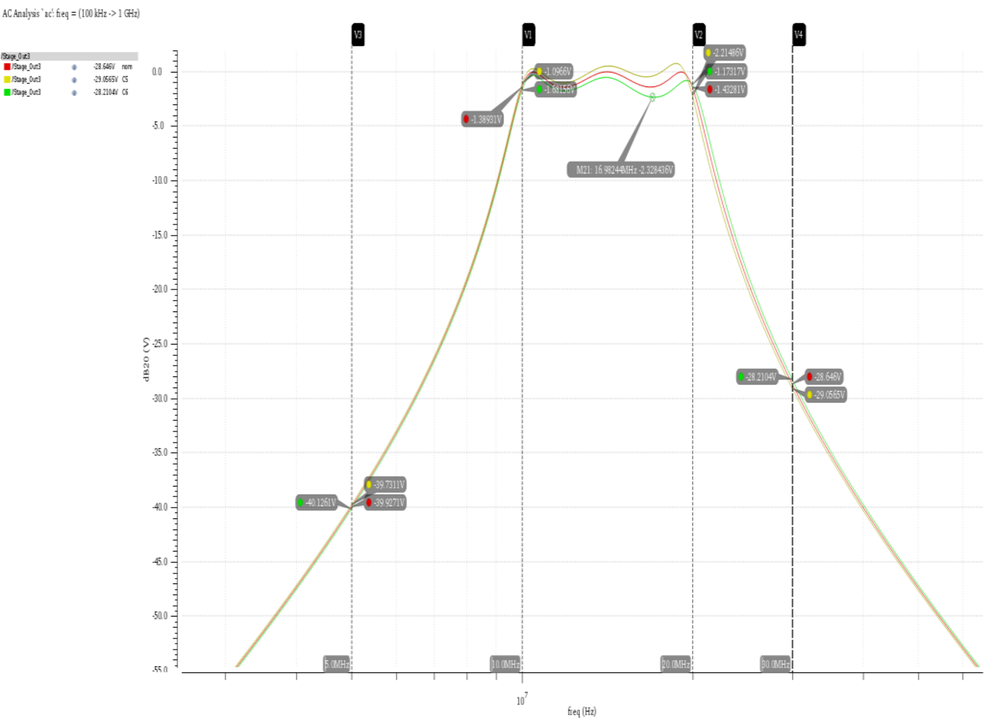


Figure 18 : Varying 1st Capacitors by 2%

```
CS1=8.1025e-12

Poles(Hz)

              Real          Imaginary      Qfactor
Pole_1        -7.389e+05    1.015e+07      6.888e+00
Pole_2        -7.389e+05    -1.015e+07     6.888e+00
Pole_3        -2.163e+06    1.397e+07      3.269e+00
Pole_4        -2.163e+06    -1.397e+07     3.269e+00
Pole_5        -1.426e+06    1.959e+07      6.888e+00
Pole_6        -1.426e+06    -1.959e+07     6.888e+00

Zeros(Hz)

              Real          Imaginary      Qfactor
Zero_1        -1.018e+03    0.000e+00      5.000e-01
Zero_2        -1.414e+03    0.000e+00      5.000e-01
Zero_3        -1.964e+03    0.000e+00      5.000e-01

Network function gain(magnitude)= 1.005e+23

CS1=8.26455e-12

Poles(Hz)

              Real          Imaginary      Qfactor
Pole_1        -7.389e+05    1.015e+07      6.888e+00
Pole_2        -7.389e+05    -1.015e+07     6.888e+00
Pole_3        -2.163e+06    1.397e+07      3.269e+00
Pole_4        -2.163e+06    -1.397e+07     3.269e+00
Pole_5        -1.398e+06    1.920e+07      6.888e+00
Pole_6        -1.398e+06    -1.920e+07     6.888e+00

Zeros(Hz)

              Real          Imaginary      Qfactor
Zero_1        -1.018e+03    0.000e+00      5.000e-01
Zero_2        -1.414e+03    0.000e+00      5.000e-01
Zero_3        -1.926e+03    0.000e+00      5.000e-01

Network function gain(magnitude)= 9.855e+22

CS1=7.94045e-12

Poles(Hz)

              Real          Imaginary      Qfactor
Pole_1        -7.389e+05    1.015e+07      6.888e+00
Pole_2        -7.389e+05    -1.015e+07     6.888e+00
Pole_3        -2.163e+06    1.397e+07      3.269e+00
Pole_4        -2.163e+06    -1.397e+07     3.269e+00
Pole_5        -1.455e+06    1.999e+07      6.888e+00
Pole_6        -1.455e+06    -1.999e+07     6.888e+00

Zeros(Hz)

              Real          Imaginary      Qfactor
Zero_1        -1.018e+03    0.000e+00      5.000e-01
Zero_2        -1.414e+03    0.000e+00      5.000e-01
Zero_3        -2.004e+03    0.000e+00      5.000e-01

Network function gain(magnitude)= 1.026e+23
```

Figure 15 : 2% 1st Capacitors Poles & Zeroes plot

Varying the gain of the Op-amps to 1000 & 100

Parameter	Nominal	C3	C4
Gain	10k	1k	100

Figure 16 : Varying gain

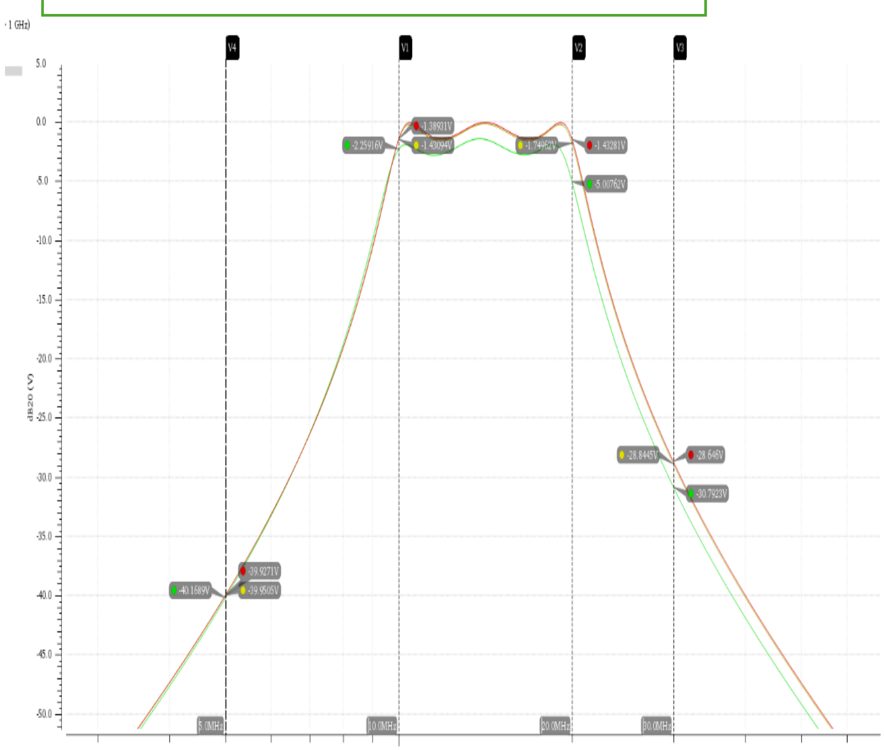


Figure 18 : Varying gain to 1000 & 100

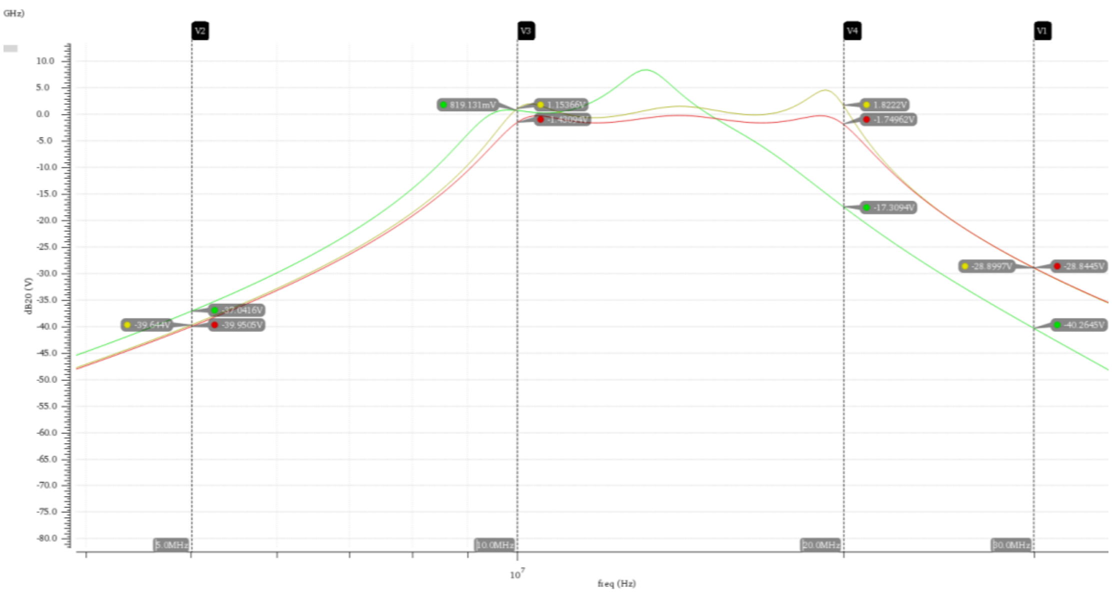
```
Gain=10000

Poles(Hz)

              Real          Imaginary      Qfactor
Pole_1        -7.389e+05    1.015e+07      6.888e+00
Pole_2        -7.389e+05    -1.015e+07     6.888e+00
Pole_3        -2.163e+06    1.397e+07      3.269e+00
Pole_4        -2.163e+06    -1.397e+07     3.269e+00
Pole_5        -1.426e+06    1.959e+07      6.888e+00
Pole_6        -1.426e+06    -1.959e+07     6.888e+00

Zeros(Hz)

              Real          Imaginary      Qfactor
Zero_1        -1.018e+03    0.000e+00      5.000e-01
Zero_2        -1.414e+03    0.000e+00      5.000e-01
Zero_3        -1.964e+03    0.000e+00      5.000e-01

Network function gain(magnitude)= 1.005e+23

Gain=1000

Poles(Hz)

              Real          Imaginary      Qfactor
Pole_1        -7.440e+05    1.013e+07      6.826e+00
Pole_2        -7.440e+05    -1.013e+07     6.826e+00
Pole_3        -2.163e+06    1.394e+07      3.261e+00
Pole_4        -2.163e+06    -1.394e+07     3.261e+00
Pole_5        -1.435e+06    1.954e+07      6.826e+00
Pole_6        -1.435e+06    -1.954e+07     6.826e+00

Zeros(Hz)

              Real          Imaginary      Qfactor
Zero_1        -1.017e+04    0.000e+00      5.000e-01
Zero_2        -1.413e+04    0.000e+00      5.000e-01
Zero_3        -1.962e+04    0.000e+00      5.000e-01

Network function gain(magnitude)= 9.875e+22

Gain=100

Poles(Hz)

              Real          Imaginary      Qfactor
Pole_1        -7.957e+05    9.909e+06      6.247e+00
Pole_2        -7.957e+05    -9.909e+06     6.247e+00
Pole_3        -2.172e+06    1.365e+07      3.181e+00
Pole_4        -2.172e+06    -1.365e+07     3.181e+00
Pole_5        -1.535e+06    1.912e+07      6.247e+00
Pole_6        -1.535e+06    -1.912e+07     6.247e+00

Zeros(Hz)

              Real          Imaginary      Qfactor
Zero_1        -1.008e+05    0.000e+00      5.000e-01
Zero_2        -1.400e+05    0.000e+00      5.000e-01
Zero_3        -1.945e+05    0.000e+00      5.000e-01

Network function gain(magnitude)= 8.286e+22
```

Figure 17 : Varying gain Poles & Zeroes values

Comment:

Decreasing the gain of Op-Amps leading to increasing in non-idealities in the Op-Amps. It also leads to increasing the number of poles and zeros as it is function of (GBW).

Add a BW limitation for the Op-amps Set the gain at 1000 and vary BW to 10MHz and 1MHz:



Comment:

Decreasing the BW of Op-Amps leading to increasing in non-idealities in the Op-Amps. It also leads to increasing the number of poles and zeros as it is function of (GBW).

Figure 19 Varying BW

```
C_BW=0,R_BW=0

Poles(Hz)

                  Real              Imaginary         Qfactor
Pole_1            -7.440e+05        1.013e+07         6.826e+00
Pole_2            -7.440e+05        -1.013e+07        6.826e+00
Pole_3            -2.163e+06        1.394e+07         3.261e+00
Pole_4            -2.163e+06        -1.394e+07        3.261e+00
Pole_5            -1.435e+06        1.954e+07         6.826e+00
Pole_6            -1.435e+06        -1.954e+07        6.826e+00

Zeros(Hz)

                  Real              Imaginary         Qfactor
Zero_1            -1.017e+04        0.000e+00         5.000e-01
Zero_2            -1.413e+04        0.000e+00         5.000e-01
Zero_3            -1.962e+04        0.000e+00         5.000e-01

Network function gain(magnitude)= 9.875e+22

C_BW=1e-10,R_BW=1000

Poles(Hz)

                  Real              Imaginary         Qfactor
Pole_1            -5.822e+05        1.010e+07         8.689e+00
Pole_2            -5.822e+05        -1.010e+07        8.689e+00
Pole_3            -1.864e+06        1.397e+07         3.782e+00
Pole_4            -1.864e+06        -1.397e+07        3.782e+00
Pole_5            -8.358e+05        1.942e+07         1.163e+01
Pole_6            -8.358e+05        -1.942e+07        1.163e+01
Pole_7            -5.084e+08        0.000e+00         5.000e-01
Pole_8            -5.197e+08        0.000e+00         5.000e-01
Pole_9            -5.251e+08        0.000e+00         5.000e-01
Pole_10           -7.137e+08        0.000e+00         5.000e-01
Pole_11           -7.502e+08        0.000e+00         5.000e-01
Pole_12           -7.559e+08        0.000e+00         5.000e-01
Pole_13           -1.393e+09        0.000e+00         5.000e-01
Pole_14           -1.596e+09        0.000e+00         5.000e-01
Pole_15           -1.596e+09        0.000e+00         5.000e-01
Pole_16           -1.598e+09        0.000e+00         5.000e-01
Pole_17           -1.610e+09        0.000e+00         5.000e-01
Pole_18           -1.616e+09        0.000e+00         5.000e-01
Pole_19           -1.626e+09        0.000e+00         5.000e-01

Zeros(Hz)

                  Real              Imaginary         Qfactor
Zero_1            -1.011e+04        0.000e+00         5.000e-01
Zero_2            -1.400e+04        0.000e+00         5.000e-01
Zero_3            -1.938e+04        0.000e+00         5.000e-01
Zero_4            -1.603e+09        0.000e+00         5.000e-01
Zero_5            -1.607e+09        0.000e+00         5.000e-01
Zero_6            -1.613e+09        0.000e+00         5.000e-01
Zero_7            7.379e+09         2.326e+09         -5.243e-01
Zero_8            7.379e+09         -2.326e+09        -5.243e-01
Zero_9            4.861e+09         6.236e+09         -8.133e-01
Zero_10           4.861e+09         -6.236e+09        -8.133e-01
```

Figure 21 Poles & Zeros

```
Zero_5            -1.607e+09        0.000e+00         5.000e-01
Zero_6            -1.613e+09        0.000e+00         5.000e-01
Zero_7            7.379e+09         2.326e+09         -5.243e-01
Zero_8            7.379e+09         -2.326e+09        -5.243e-01
Zero_9            4.861e+09         6.236e+09         -8.133e-01
Zero_10           4.861e+09         -6.236e+09        -8.133e-01
Zero_11           6.165e+08         8.165e+09         -6.640e+00
Zero_12           6.165e+08         -8.165e+09        -6.640e+00
Zero_13           -4.001e+09        7.503e+09         1.063e+00
Zero_14           -4.001e+09        -7.503e+09        1.063e+00
Zero_15           -7.528e+09        4.457e+09         5.811e-01
Zero_16           -7.528e+09        -4.457e+09        5.811e-01
Zero_17           -8.845e+09        0.000e+00         5.000e-01

Network function gain(magnitude)= 4.157e+02

C_BW=1e-09,R_BW=1000

Poles(Hz)

                  Real              Imaginary         Qfactor
Pole_1            6.938e+05         9.474e+06         -6.846e+00
Pole_2            6.938e+05         -9.474e+06        -6.846e+00
Pole_3            7.260e+05         1.314e+07         -9.066e+00
Pole_4            7.260e+05         -1.314e+07        -9.066e+00
Pole_5            2.839e+06         1.645e+07         -2.939e+00
Pole_6            2.839e+06         -1.645e+07        -2.939e+00
Pole_7            -4.395e+07        0.000e+00         5.000e-01
Pole_8            -5.059e+07        0.000e+00         5.000e-01
Pole_9            -5.261e+07        0.000e+00         5.000e-01
Pole_10           -7.978e+07        0.000e+00         5.000e-01
Pole_11           -8.275e+07        0.000e+00         5.000e-01
Pole_12           -8.417e+07        0.000e+00         5.000e-01
Pole_13           -1.393e+08        0.000e+00         5.000e-01
Pole_14           -1.622e+08        0.000e+00         5.000e-01
Pole_15           -1.631e+08        0.000e+00         5.000e-01
Pole_16           -1.654e+08        0.000e+00         5.000e-01
Pole_17           -1.754e+08        0.000e+00         5.000e-01
Pole_18           -1.810e+08        0.000e+00         5.000e-01
Pole_19           -1.890e+08        0.000e+00         5.000e-01

Zeros(Hz)

                  Real              Imaginary         Qfactor
Zero_1            -9.561e+03        0.000e+00         5.000e-01
Zero_2            -1.298e+04        0.000e+00         5.000e-01
Zero_3            -1.747e+04        0.000e+00         5.000e-01
Zero_4            -1.695e+08        0.000e+00         5.000e-01
Zero_5            -1.734e+08        0.000e+00         5.000e-01
Zero_6            -1.789e+08        0.000e+00         5.000e-01
Zero_7            1.652e+09         0.000e+00         -5.000e-01
Zero_8            1.305e+09         1.014e+09         -6.333e-01
Zero_9            1.305e+09         -1.014e+09        -6.333e-01
Zero_10           4.305e+08         1.613e+09         -1.939e+00
Zero_11           4.305e+08         -1.613e+09        -1.939e+00
Zero_12           -6.024e+08        1.583e+09         1.405e+00
Zero_13           -6.024e+08        -1.583e+09        1.405e+00
Zero_14           -1.416e+09        9.631e+08         6.046e-01
Zero_15           -1.416e+09        -9.631e+08        6.046e-01
```

Figure 20 Poles & Zeros

We can see that there is a new poles and zeros appeared because of the non-ideality of op-amps.

- We can say that high quality factor of or system make this change more worth in our system.

•	-15%	Nominal	15%
Min Stopband Attenuation	1.3945	1.433	1.398
Max Stopband Attenuation	20.3	28.646	34.5

	-2%	Nominal	2%
Min Stopband Attenuation	1.173	1.433	2.215
Max Stopband Attenuation	28.21	28.646	29.0556

Gain	100	Nominal (10000)	1000
Min Stopband Attenuation	5	1.433	1.75
Max Stopband Attenuation	30.8	28.646	28.845

BW	1M	Nominal (Infinity)	10M
Min Stopband Attenuation	17.3	1.75	1.822
Max Stopband Attenuation	40.26	28.845	28.9

4. Matlab Code

```
% Define the numerator and denominator coefficients for the transfer function H(s)
% These coefficients are specified for a high-order system.
numerator = [1.0055e+23, 0, 0, 0];   % Coefficients of the numerator polynomial of H(s)
denominator =
[1,54356436.5638108,2.81252429808991e+16,9.58909261436301e+23,2.22068017524791e+32,3.3886790896
1806e+39,4.92231267110556e+47]; % Coefficients of the denominator polynomial of H(s)
% Create the transfer function H(s) using the 'tf' function
H = tf(numerator, denominator);
% Compute the poles of the transfer function H(s) and convert them to Hz
% Poles are the roots of the denominator polynomial of the transfer function.
poles_in_Hz = pole(H) / (2 * pi);
% Display the computed poles in Hz
disp('Poles of the transfer function in Hz:');
disp(poles_in_Hz);
% Plot the Bode plot of the transfer function H(s)
% The Bode plot shows the magnitude and phase response of the system over a range of
frequencies.
figure;
bode(H), grid on;
title('Bode Plot of the Transfer Function H(s)');
xlabel('Frequency (Hz)');
ylabel('Phase (degrees)');
```

- Our Repository and fall code

https://github.com/MGMA10/Biquad-BandPass-filter-based-on-Chebyshev-

- Our MATLAB codes

https://github.com/MGMA10/Biquad-BandPass-filter-based-on-Chebyshev-/blob/main/prog.m

https://github.com/MGMA10/Biquad-BandPass-filter-based-on-Chebyshev-/blob/main/IC_P2.m